REPORT No. 140.

LIFT AND DRAG EFFECTS OF WING-TIP RAKE.

By A. F. ZAHM, R. M. BEAR, AND G. C. HILL,

Bureau of Construction and Repair, Navy Department.

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INTRODUCTION.

In order to furnish some needed data for wing end design, models of the Royal Aircraft Factory 6, Albatross, and Sloane aerofoils were made, verified, and tested at 35 miles per hour in the 4 by 4 foot wind tunnel, to determine the lift and drag effects of varying the amount of rake of the wing tips. The results are submitted in this report for publication by the National Advisory Committee for Aeronautics by permission of the Bureau of Construction and Repair, Navy Department.

DESCRIPTION OF MODELS.

Figures 1, 2, and 3 give the chief dimensions of these models; also their offsets, both specified and actual. The models were planed out of a bronze casting, as usual, and were then shaped at the ends by running fine saw cuts across the finished form; first obliquely to give the longer tip, as shown, then squarely to detach this. Dowel pins were provided by which the tips could in each case be readily slipped into their proper position or removed. The longer tip, after its test, was amputated to make the shorter one. The straight oblique edges of the tips were rounded to an approximately circular bevel to diminish the head resistance. The surface of the aerofoils was not shellacked nor polished but left smooth and bright as it came from the automatic planer.

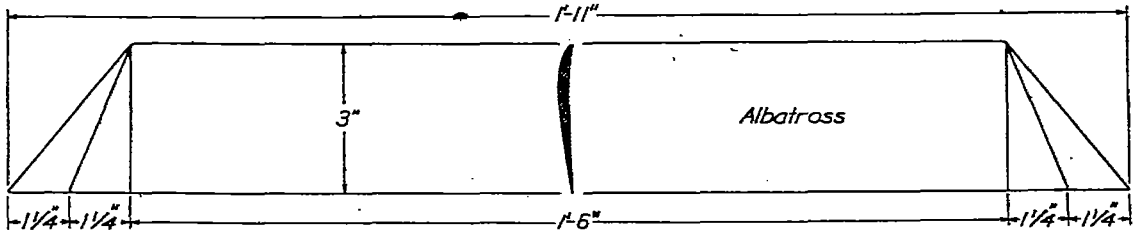

Fig 1.—Dimensions of Albatross aerofoil.

[All dimensions given as decimal part of chord.]

Distance from leading edge	0.000	0.010	0.025	0.050	0.100	0.150	0.200	0.250	0.300	0.400	0.500	0.600	0.700	0.800	0.900	0.950	0.995	1.000
Upper camber:																		
Specified	.0073	.0197	.0337	.050	.0707	.0827	.090	.094	.0963	.094	.0857	.0733	.060	.043	.0247	.015	.0053	.0037
Actual	.0073	.0213	.035	.051	.070	.081	.0873	.0913	.0933	.0910	.083	.0707	.057	.0403	.0223	.0127	.0027	
Lower camber:																		
Specified	.0073	.000	.002	.006	.0127	.0177	.0213	.0237	.025	.0263	.025	.0217	.0177	.0127	.0067	.003	.000	.0037
Actual	.0047	.000	.0013	.0057	.0123	.0173	.021	.024	.0263	.0277	.0267	.0233	.0197	.0147	.0087	.004	.002	

Offsets (measured from and ⊥ to chord.)

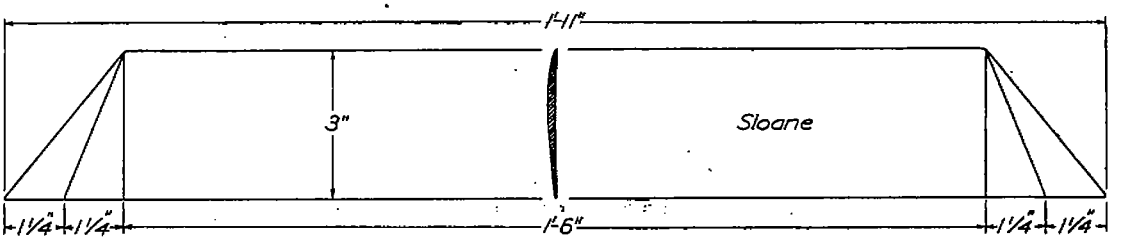

FIG. 2.—Dimension of Sloane aerofoil.

[All dimensions given as decimal part of chord.]

Distance from leading edge	0.000	0.025	0.050	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	0.982	1.000
Upper camber:														
Specified	.007	.0257	.034	.0437	.0527	.0568	.0583	.058	.0483	.041	.0327	.0213	.....	.0057
Actual	.007	.0257	.0347	.0443	.0517	.055	.0547	.0517	.0467	.0393	.0303	.0190	.0066	.....
Lower camber:														
Specified	.007	.0007	.000	.0013	.005	.0063	.0057	.0047	.0037	.0033	.002	.0007	.....	.0057
Actual	.0023	.000	.000	.0017	.0043	.0057	.005	.0043	.003	.002	.0013	.0007	.0053	.....

Offsets (measured from and ⊥ to chord).

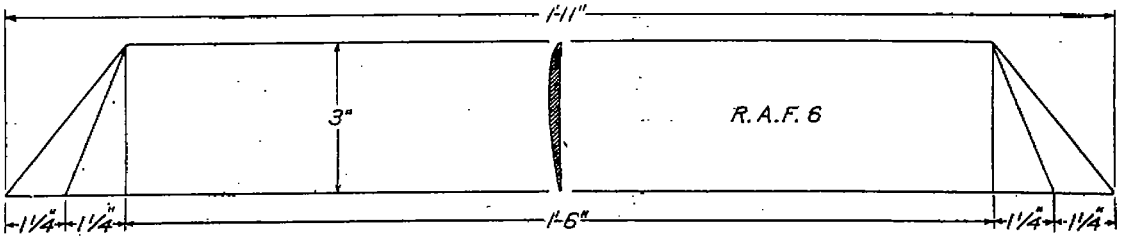

FIG. 3.—Dimensions of R. A. F. 6 aerofoil.

[All dimensions given as decimal part of chord.]

Distance from leading edge	0.000	0.0123	0.025	0.050	0.100	0.200	0.300	0.400	0.050	0.600	0.700	0.800	0.900	1.000
Upper camber:														
Specified	.005	.022	0.32	.044	.060	.074	.0767	.075	.071	.0647	.0557	.044	.027	.005
Actual	.005	.024	.034	.0467	.0623	.0763	.0783	.0763	.0723	.066	.0567	.0453	.0283	.0067
Lower camber:														
Specified	.005	.000	.0007	.002	.004	.0067	.0073	.0067	.0053	.0043	.0033	.002	.001	.005
Actual	.0043	.000	.0003	.0017	.0037	.0063	.0077	.008	.007	.0053	.004	.003	.0013	.005

Offsets (measured from and ⊥ to chord).

METHOD OF TEST.

During the tests each aerofoil in turn was held vertical and well upstream with a thin flat steel bar which pointed horizontally forward from the tip of the balance spindle and was slitted at its end, made to clamp the after middle of the model, and soldered to it. Thus the resultant drag at all angles of attack was horizontal and on a level with the aerofoil center. After a complete set of lift and drag readings at all incidences from $-6°$ to $16°$ were taken with square, medium-raked, and long-raked tips, the tests were repeated with the holder unsoldered from the aerofoil but not removed. During these check runs the model was set in incidence with a dummy end spindle reaching down from the tunnel ceiling, and was steadied with horizontal stay wires fixed to the tunnel walls.

RESULTS OF THE TEST.

Tables I to XII, inclusive, and figures 4, 5, and 6 give the data of the test and the values derived therefrom. The general effect can best be seen in the comparative Tables IV, VIII, and XII. These show that for all three of the aerofoils and at practically all angles of incidence the lift coefficient is greater with the half tip, and still greater with the whole tip, than with the square one. The percentage increase is given in the columns marked "lift coefficient."

The columns of drag coefficients show that there is little to choose between the half and the whole tip, but that both give a considerably greater drag coefficient than that of the standard square tipped aerofoil. A few exceptions to this general statement may be noted in the drag coefficient columns. As seen in the last two columns of these tables, the general effect of the

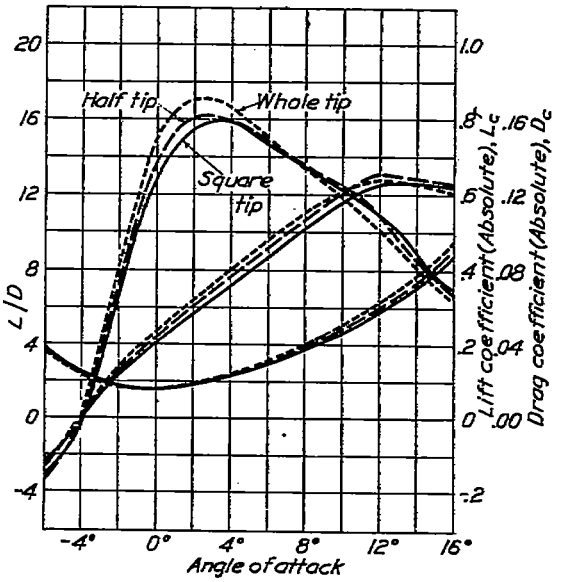

FIG. 4.—Albatross aerofoil. Lift and drag coefficients and L/D. Air speed 35 m. p. h.

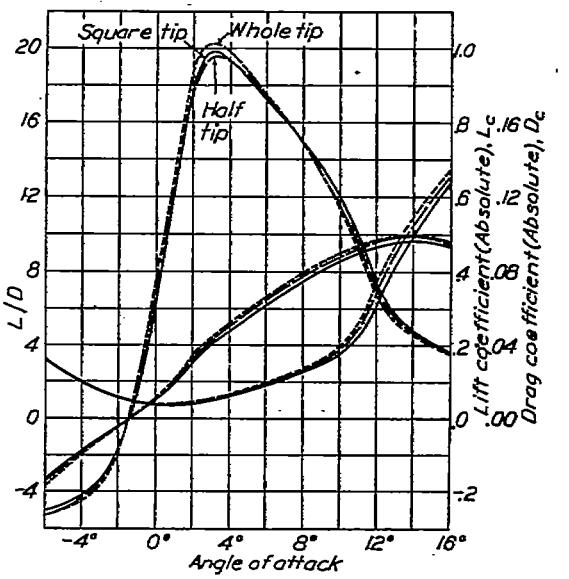

FIG. 5.—Sloane aerofoil. Lift and drag coefficients and L/D. Air speed 35 m. p. h.

raked tips is to improve the lift/drag of the aerofoils at all except the higher angles. At incidences below the angles of greatest efficiency the raked tips on all three of the aerofoils cause a decided improvement of efficiency which is greater for the long raked tip than for the short one.

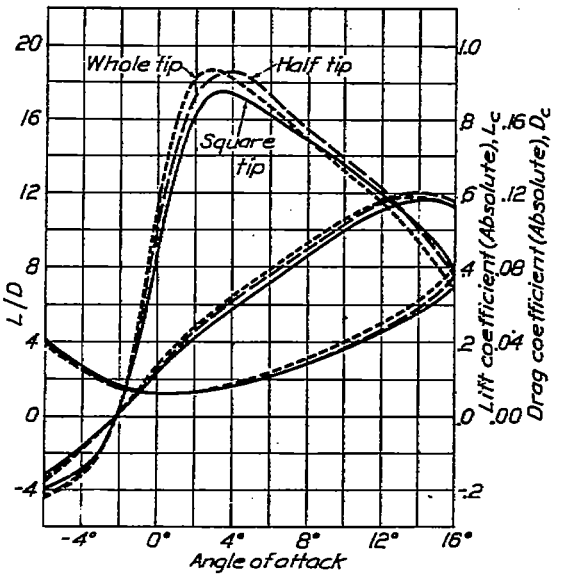

FIG. 6.—R. A. F 6 aerofoil. Lift and drag coefficients and L/D. Air speed 35 m. p. h.

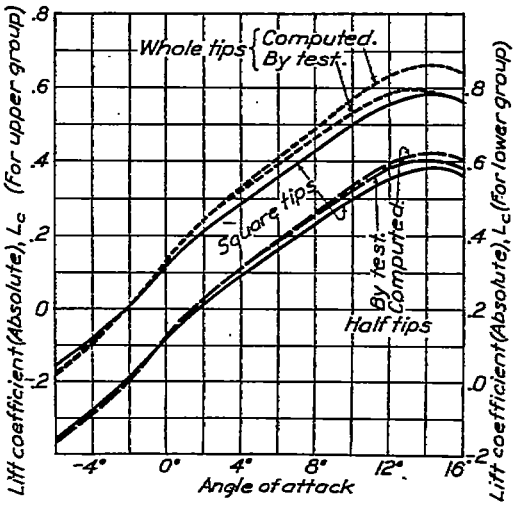

FIG. 7.—Albatross aerofoil. Lift coefficients for various tips. Air speed 35 m. p. h.

ACTUAL v. COMPUTED VALUES.

Figures 7, 8, and 9 give the foregoing lift coefficients plotted against computed values for raked tips. The method of computing the effect of rake was taken from Reports & Memoranda No. 575 of the British Advisory Committee for Aeronautics, and need not be given in

detail here. Over a considerable range of all the graphs the computed values agree closely with the observed values for raked tips; but in the region of maximum lift the computed values are increasingly too large.

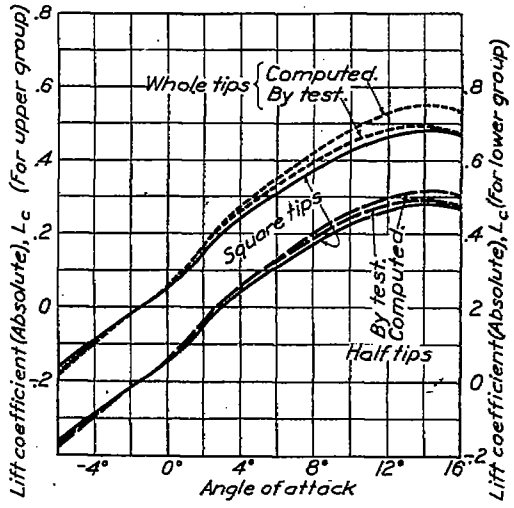

FIG. 8.—Sloane aerofoil. Lift coefficient for various tips. Air speed 35 m. p. h.

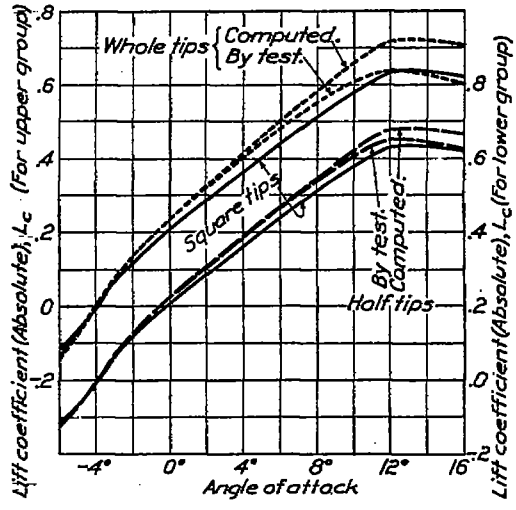

FIG. 9.—R. A. F. 6 aerofoil. Lift coefficient for various tips. Air speed 35 m. p. h.

Though no general conclusions can be drawn from such a limited study, it furnishes some evidence in favor of the common practice of pointing the wing tips obliquely backward. Doubtless the end effect for wings, like that for struts, is largely due to local changes of flow, and hence must be relatively of less importance as the aspect ratio increases. Both phenomena could be better elucidated by mapping the flow in the region where the overspill occurs, and noting the improved smoothness caused by sharpening the ends.

TABLE I.—*Lift and drag coefficients and lift/drag—18 by 3 inches R. A. F. 6 aerofoil without wing tips—air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient L_c.	Drag coefficient D_c.	Lift/drag.	Lift coefficient K_y.	Drag coefficient K_x.
− 6	−0.1584	0.0403	− 3.93	−0.000809	0.0002058
− 3	− .0351	.0214	− 1.78	− .000194	.0001095
− 1	+ .0618	.0145	+ 4.26	+ .000316	.0000740
0	.1189	.0130	9.15	.000607	.0000666
+ 1	.1709	.0127	13.48	.000873	.0000645
2	.2138	.0132	16.20	.001092	.0000672
3	.2528	.0145	17.43	.001291	.0000742
4	.2897	.0167	17.35	.001479	.0000851
6	.3613	.0223	16.20	.001845	.0001138
8	.4327	.0291	14.87	.002210	.0001486
10	.5013	.0372	13.48	.002560	.0001902
12	.5562	.0465	11.94	.002835	.0002374
14	.5834	.0568	10.27	.002979	.0002898
+16	+ .5630	.0729	+ 7.72	+ .002875	.0003725

TABLE II.—*Lift and drag coefficients and lift/drag—18 by 3 inches R. A. F. 6 aerofoil with half wing tips—air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient L_c.	Drag coefficient D_c.	Lift/drag.	Lift coefficient K_y.	Drag coefficient K_x.
− 6	−0.1726	0.0406	− 4.25	−0.000882	0.0002074
− 3	− .0412	.0205	− 2.01	− .000211	.0001048
− 1	+ .0669	.0141	+ 4.74	+ .000342	.0000720
0	.1307	.0128	10.21	.000667	.0000653
+ 1	.1849	.0126	14.64	.000945	.0000645
2	.2308	.0133	17.39	.001179	.0000678
3	.2723	.0147	18.47	.001391	.0000753
4	.3114	.0167	18.61	.001591	.0000855
6	.3886	.0221	17.38	.001960	.0001127
8	.4534	.0291	15.56	.002316	.0001449
10	.5231	.0375	13.93	.002672	.0001917
12	.5848	.0472	12.38	.002987	.0002411
14	.6038	.0589	10.25	.003084	.0003008
+16	+ .5848	.0779	+ 7.51	+ .002987	.0003976

TABLE III.—*Lift and drag coefficients and lift/drag—18 by 3 inches R. A. F. 6 aerofoil with whole wing tips—air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient L_a.	Drag coefficient D_a.	Lift/drag.	Lift coefficient K_y.	Drag coefficient K_x.
− 6	−0.1753	0.0397	− 4.42	−0.000395	0.0002025
− 3	− .0407	.0204	− 1.99	− .000208	.0001043
− 1	+ .0741	.0133	+ 5.35	+ .000378	.0000707
0	.1383	.0125	11.03	.000706	.0000640
+ 1	.1952	.0124	15.80	.000996	.0000630
2	.2415	.0133	18.18	.001233	.0000678
3	.2829	.0152	18.57	.001444	.0000777
4	.3219	.0177	18.21	.001643	.0000902
6	.3957	.0233	16.64	.002020	.0001213
8	.4561	.0314	14.86	.002379	.0001601
10	.5336	.0405	13.18	.002724	.0002065
12	.5842	.0505	11.57	.002982	.0002577
14	.5942	.0631	9.42	.003033	.0003222
+16	+ .5621	.0829	+ 6.78	+ .002869	.0004233

TABLE IV.—*Comparison of 18 by 3 inches R. A. F. 6 aerofoil characteristics for different wing tips—aerofoil without wing tips taken as standard air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient.		Drag coefficient.		Lift/drag.	
	Half wing tips.	Whole wing tips.	Half wing tips.	Whole wing tips.	Half wing tips.	Whole wing tips.
− 6	1.090	1.106	1.007	0.935	1.081	1.125
− 3	1.081	1.067	.958	.953	1.118	1.146
− 1	1.082	1.198	.972	.962	1.112	1.255
0	1.100	1.163	.935	.962	1.116	1.205
+ 1	1.051	1.142	.992	.977	1.087	1.174
2	1.079	1.129	1.007	1.007	1.073	1.122
3	1.075	1.118	1.013	1.043	1.060	1.065
4	1.068	1.108	1.000	1.060	1.072	1.050
6	1.061	1.095	.991	1.067	1.073	1.028
8	1.048	1.077	1.000	1.079	1.046	1.000
10	1.044	1.065	1.008	1.038	1.034	.978
12	1.053	1.052	1.013	1.047	1.036	.970
14	1.035	1.018	1.037	1.110	1.000	.917
+16	1.038	.999	1.068	1.136	.973	.878

TABLE V.—*Lift and drag coefficients and lift/drag—18 by 3 inches albatross aerofoil without wing tips—air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient L_a.	Drag coefficient D_a.	Lift/drag.	Lift coefficient K_y.	Drag coefficient K_x.
− 6	−0.1156	0.0392	− 2.95	−0.000591	0.0002002
− 3	+ .0652	.0205	+ 3.18	+ .000333	.0001047
− 1	.1646	.0162	10.20	.000841	.0000825
0	.2072	.0161	12.86	.001058	.0000823
+ 1	.2471	.0170	14.50	.001262	.0000870
2	.2860	.0185	15.42	.001460	.0000947
3	.3242	.0205	15.85	.001656	.0001042
4	.3623	.0228	15.89	.001850	.0001164
6	.4372	.0297	14.70	.002233	.0001519
8	.5107	.0379	13.46	.002608	.0001937
10	.5780	.0470	12.29	.002952	.0002400
12	.6313	.0578	10.92	.003224	.0002951
14	.6311	.0713	8.84	.003223	.0003643
+16	+ .6194	.0883	+ 7.01	+ .003163	.0004509

TABLE VI.—*Lift and drag coefficients and lift/drag—18 by 3 inches albatross aerofoil with half wing tips—air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient L_a.	Drag coefficient D_a.	Lift/drag.	Lift coefficient K_y.	Drag coefficient K_x.
− 6	−0.1215	0.0385	− 3.15	−0.000621	0.0001968
− 3	+ .0736	.0209	+ 3.52	+ .000376	.0001066
− 1	.1798	.0161	11.16	.000919	.0000822
0	.2237	.0162	13.82	.001143	.0000826
+ 1	.2630	.0172	15.27	.001343	.0000879
2	.3066	.0190	16.14	.001566	.0000971
3	.3463	.0214	16.21	.001771	.0001093
4	.3849	.0242	15.92	.001966	.0001235
6	.4606	.0312	14.77	.002353	.0001593
8	.5362	.0394	13.61	.002739	.0002013
10	.6082	.0486	12.52	.003107	.0002481
12	.6521	.0599	10.89	.003331	.0003059
14	.6417	.0740	8.67	.003278	.0003779
+16	+ .6263	.0919	+ 6.81	+ .003199	.0004695

TABLE VII.—*Lift and drag coefficients and lift/drag—18 by 3 inches albatross aerofoil with whole wing tips—air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient L_c.	Drag coefficient D_c.	Lift/drag.	Lift coefficient K_y.	Drag coefficient K_x.
− 6	−0.1250	0.0381	− 3.28	−0.000638	0.0001946
− 3	+ .0796	.0206	+ 3.86	+ .000406	.0001052
− 1	.1925	.0159	12.08	.000983	.0000814
0	.2368	.0160	14.81	.001209	.0000816
+ 1	.2802	.0171	16.43	.001430	.0000871
2	.3224	.0189	17.03	.001646	.0000966
3	.3639	.0215	17.05	.001858	.0001089
4	.4038	.0243	16.59	.002061	.0001242
6	.4804	.0318	15.08	.002452	.0001653
8	.5516	.0409	13.46	.002816	.0002090
10	.6079	.0512	11.86	.003103	.0002615
12	.6410	.0632	10.14	.003272	.0003226
14	.6246	.0778	8.04	.003189	.0003970
+16	+ .6043	.0956	+ 6.33	+ .003085	.0004878

TABLE VIII.—*Comparison of 18 by 3 inches albatross aerofoil characteristics for different wing tips—aerofoil without wing tips taken as standard—air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient.		Drag coefficient.		Lift/drag.	
	Half wing tips.	Whole wing tips.	Half wing tips.	Whole wing tips.	Half wing tips.	Whole wing tips.
− 6	1.050	1.081	0.983	0.972	1.067	1.111
− 3	1.128	1.220	1.019	1.004	1.107	1.213
− 1	1.090	1.169	.994	.982	1.094	1.184
0	1.079	1.142	1.006	.994	1.074	1.151
+ 1	1.063	1.133	1.011	1.005	1.053	1.132
2	1.072	1.127	1.027	1.021	1.046	1.104
3	1.069	1.121	1.044	1.038	1.022	1.075
4	1.062	1.114	1.061	1.065	1.001	1.044
6	1.053	1.098	1.060	1.070	1.005	1.026
8	1.050	1.080	1.039	1.079	1.011	1.000
10	1.052	1.051	1.033	1.053	1.018	.965
12	1.032	1.015	1.037	1.093	.998	.929
14	1.016	.990	1.037	1.090	.981	.909
+16	1.011	.976	1.031	1.082	.972	.903

TABLE IX.—*Lift and drag coefficients and lift/drag—18 by 3 inches Sloane aerofoil without wing tips—air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient L_c.	Drag coefficient D_c.	Lift/drag.	Lift coefficient K_y.	Drag coefficient K_x.
− 6	−0.1645	0.0330	− 4.98	−0.000840	0.0001686
− 3	− .0518	.0156	− 3.31	− .000265	.0000799
− 1	+ .0151	.0091	+ 1.66	+ .000077	.0000466
0	.0509	.0077	6.60	.000260	.0000394
+ 1	.0944	.0076	12.36	.000482	.0000390
2	.1513	.0085	17.84	.000772	.0000433
3	.2016	.0102	19.80	.001029	.0000520
4	.2396	.0124	19.32	.001224	.0000633
6	.3091	.0181	17.10	.001579	.0000923
8	.3739	.0251	14.92	.001910	.0001279
10	.4276	.0357	11.99	.002184	.0001821
12	.4638	.0623	7.45	.002369	.0003179
14	.4809	.1001	4.80	.002456	.0005114
+16	+ .4677	.1272	+ 3.68	+ .002389	.0006498

TABLE X.—*Lift and drag coefficients and lift/drag—18 by 3 inches Sloane aerofoil with half wing tips—air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient L_c.	Drag coefficient D_c.	Lift/drag.	Lift coefficient K_y.	Drag coefficient K_x.
− 6	−0.1717	0.0326	− 5.27	−0.000877	0.0001661
− 3	− .0532	.0156	− 3.42	− .000272	.0000796
− 1	+ .0190	.0094	+ 2.03	+ .000097	.0000478
0	.0569	.0083	6.90	.000291	.0000421
+ 1	.1047	.0084	12.45	.000535	.0000429
2	.1652	.0094	17.58	.000844	.0000480
3	.2140	.0110	19.52	.001093	.0000560
4	.2523	.0131	19.24	.001289	.0000670
6	.3242	.0187	17.38	.001656	.0000952
8	.3911	.0263	14.85	.001998	.0001345
10	.4410	.0383	11.53	.002253	.0001954
12	.4811	.0681	7.06	.002457	.0003480
14	.4917	.1042	4.72	.002511	.0005322
+16	+ .4795	.1301	+ 3.68	+ .002449	.0006646

TABLE XI.—*Lift and drag coefficients and lift/drag—18 by 3 inches Sloane aerofoil with whole wing tips—air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient L_c.	Drag coefficient D_c.	Lift/drag.	Lift coefficient K_y.	Drag coefficient K_x.
− 6	−0.1803	0.0329	− 5.49	−0.000920	0.0001677
− 3	− .0554	.0152	− 3.65	− .000283	.0000775
− 1	.0202	.0092	2.20	.000103	.0000468
0	.0612	.0062	7.50	.000312	.0000416
1	.1097	.0063	13.26	.000560	.0000422
2	.1737	.0093	18.64	.000887	.0000476
3	.2233	.0110	20.23	.001140	.0000563
4	.2620	.0133	19.80	.001343	.0000678
6	.3340	.0192	17.43	.001705	.0000978
8	.3996	.0268	14.89	.002040	.0001369
10	.4486	.0396	11.32	.002290	.0002023
12	.4833	.0721	6.70	.002465	.0003682
14	.4936	.1084	4.55	.002520	.0005535
16	.4755	.1339	3.55	.002428	.0006834

TABLE XII.—*Comparison of 18 by 3 inches Sloane aerofoil characteristics for different wing tips—Aerofoil without wing tips taken as standard—Air speed 35 miles per hour.*

Angle of incidence (degrees).	Lift coefficient.		Drag coefficient.		Lift/drag.	
	Half wing tips.	Whole wing tips.	Half wing tips.	Whole wing tips.	Half wing tips.	Whole wing tips.
− 6	1.044	1.096	0.958	0.937	1.058	1.102
− 3	1.027	1.069	1.000	.975	1.033	1.102
− 1	1.258	1.338	1.032	1.010	1.222	1.325
0	1.117	1.202	1.077	1.064	1.045	1.136
+ 1	1.109	1.162	1.104	1.091	1.007	1.072
2	1.091	1.148	1.106	1.094	.985	1.045
3	1.062	1.108	1.078	1.078	.986	1.021
4	1.053	1.093	1.056	1.072	.996	1.025
6	1.048	1.080	1.033	1.061	1.017	1.002
8	1.046	1.068	1.047	1.067	.995	.998
10	1.031	1.049	1.072	1.109	.962	.944
12	1.037	1.042	1.092	1.157	.947	.899
14	1.022	1.026	1.041	1.083	.983	.948
+16	1.025	1.016	1.023	1.029	1.000	.965